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THE THERMODYNAMIC CALCULATION OF OFFSET SHAFTS ROTARY ENGINE IDEAL CYCLE WITH EXTERNAL HEAT SUPPLY

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ABSTRACT

A specific ideal thermodynamic cycle was determined, quite accurately describing the work of offset shafts rotary heat engine with external heat supply. A thermal calculation was made and the values of thermodynamic condition parameters were obtained at all characteristic points of the cycle. Evaluation of the rotary heat engine efficiency was produced with mathematical method.

KEYWORDS: The Rotary Engine With External Heat Supply, Ideal Thermodynamic Cycle, Thermodynamic Condition Parameters, Thermal Efficiency, Heat & Work

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HIGHLIGHTS

The external combustion rotary engine was developed.

The rotary engine scheme was presented.

The thermal efficiency of the thermodynamic cycle was determined.

INTRODUCTION

Lately, researchers in all countries have attempted to create an efficient heat engine, which had allowed converting the heat supplied to the working fluid with minimal loss during the fuel combustion into mechanical work.

Since 1870, the internal combustion engine is the main power plant which is capable to convert burnt fuel chemical energy into mechanical work effectively. The direct thermodynamic cycle is basis of any internal combustion engine operation.

The heat engine work efficiency may be evaluated by using the thermal efficiency. Internal combustion engine thermal efficiency ranges from 0.3 to 0.6, depending on the heat engine power system. To achieve a higher value of thermal efficiency is not possible due to the large amount of running engine heat losses, which are characterized by the entropy S value. Due to the entropy S value and the thermal efficiency value for all internal combustion engines are limiting, scientists are currently attempting to create an alternative power plant of an external combustion engine.

This subject of research has acquired its relevance in connection with the new technology development and with the advent of new materials. The main positive aspect of these power plant types is environmental friendliness as compared with internal combustion engines. Another positive thing is the possibility of using as an external heat source of any solid, liquid or gaseous states of fuel.

The Stirling Engine is one of the most famous designs of power units with external heat supply. A characteristic feature of this heat engine is: it operates on a closed thermodynamic cycle and regenerative heat exchanger is included in its design.

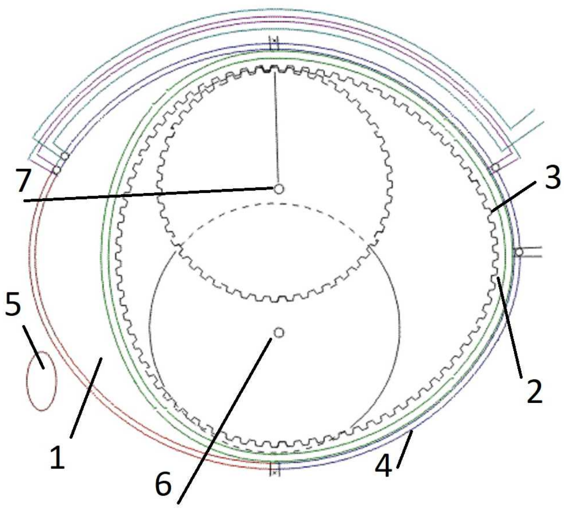
Features of various designs of already existing Stirling engines are considered in work [1], also there are its description and the presented power unit efficiency evaluation. In addition, comparative analysis of the Stirling cycle with Carnot direct ideal cycle is given in this research.

The model of the Stirling external combustion engine crank drive mechanism is considered in work [2]. The thermodynamic analysis of the processes occurring inside the engine is given. The calculated value of the average heat transfer coefficient between the working fluid and the piston surface and the heat flux transferred from working fluid and the piston are determined in this work by using the similarity equation.

An analysis of the literature showed that the existing design of Stirling engine crank drive mechanisms are very cumbersome and suggest significant losses of mechanical energy. Also, great difficulties arise when deciding the issue of sealing the working fluid. Therefore, it’s necessary to create new variants of the external combustion engine schemes. The most preferred option is to create an external combustion rotary engine.

MATERIALS AND METHODS

One of the variants of the external combustion rotary engine was developed by PhD of Technics Ravil A. Latypov [3, 4]. A diagram of this power plant is presented in figure 1.



1. Hot variable volume cavity
2. Cold variable volume cavity
3. Rotor
4. Body
5. External heat source (gas burner)
6, 7. Two offset power take – off shafts

Figure 1: Diagram of an Offset Shafts Rotary Engine with External Heat Supply

The design of the presented heat engine can be described as a planetary type rotary engine with external heat supply. This engine has a hot 1 and cold 2 variable volume cavities. These cavities are formed by the rotor 3 and the housing 4 working surfaces. The thermodynamic processes are produced in these cavities. When the rotor rotates between the body and the rotor, hot 1 and cold 2 cavities of variable volume will be formed. During one revolution of the rotor shaft, 12 thermodynamic processes occur in the hot and cold cavities.

Thus, the presented external combustion rotary engine consists of:

A rotor 3, a body 4, two cavities hot 1 and cold 2, an external heat source (gas burner) 5, sealing elements, valves and two offset power take – off shafts 6, 7. Hot and cold cavities are connected to each other using a separate pipe.

The air is served to the cold cavity through the inlet pipe. Exhaust gases are gone from the hot cavity to the environment through the exhaust pipe. In this case, the exhaust gases give up their heat to the intermediate coolant circulating inside the recuperative heat exchanger.

The operation of an offset shafts rotary engine with external heat supply is carried out as follows. The working fluid (portion of the air) enters the cold cavity through the inlet pipe and the inlet valve. Further, the working fluid is compressed inside the cold cavity with heat removed from the heated air into the environment. Then a portion of air from the cold cavity enters the pipe connecting the two cavities, while the working fluid receives heat from the coolant circulating inside the recuperative heat exchanger. In the hot cavity, the working fluid expands due to the heat supply from an external source of combustion. At the same time, the exhaust gases move from the hot cavity to the environment due to some rotor torque through the exhaust pipe. Along the way, the exhaust gases give up their heat to the regenerative heat exchanger. Two power take – off shafts acquire some torque due to the rotor rotation. Further, the processes occurring inside the engine are repeated.

RESULTS

Analysis of the thermodinamic processes occurring inside the external combustion fuel rotary engine allowed establishing that most accurately cycle is the ideal Stirling cycle [5]. It consists of two isotherms and two isochores (figure 2).

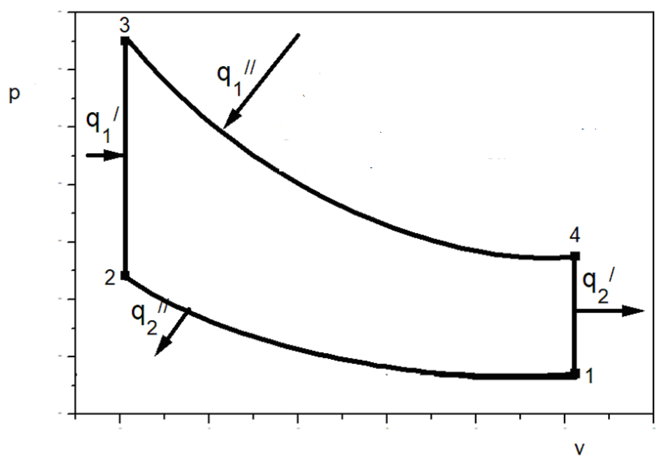


Figure 2: The Scheme of Operation of the External Combustion Rotary Engine in P, V Coordinates

The ideal Stirling cycle p, v diagram allows to calculate the thermodynamic parameters of a state at any of its characteristic points.

An ideal gas with initial parameters p_1, v_1 and T_2 is compressed along the isotherm **1 – 2** to point **2** with heat removal $q_2^{//} = R \cdot T_2 \cdot \ln\left(\frac{v_1}{v_2}\right)$ to a cold source. Further along the isochore **2 – 3** the working fluid is informed of the amount of heat $q_1^{/} = c_v \cdot (T_1 - T_2)$ from the heat exchanger. From point **3** the working fluid expands in an isotherm **3 – 4** with the supply of heat $q_1^{//} = R \cdot T_1 \cdot \ln\left(\frac{v_4}{v_3}\right) = R \cdot T_1 \cdot \ln\left(\frac{v_1}{v_2}\right)$ from a hot source. Finally, from the isochore **4 – 1** the working fluid returns to its original state, while the amount of heat $q_2^{/} = c_v \cdot (T_1 - T_2)$ is removed to the heat exchanger.

Characteristics of the cycle are the degree of compression $\varepsilon = \frac{v_1}{v_2}$ and the degree of pressure increase $\lambda = \frac{p_3}{p_2}$.

Define the parametrs of the working fluid in all characteristic points of the Stirling cycle:

At point 1

- A pressure p_1 is set;
- An absolute temperature T_2 is set;
- A specific volume v_1

$$v_1 = \frac{R \cdot T_2}{p_1} \tag{1}$$

At point 2

- A specific volume v_2

$$\varepsilon = \frac{v_1}{v_2} \Rightarrow v_2 = \frac{v_1}{\varepsilon} \tag{2}$$

- An absolute temperature T_2 is known and does not change as the process 1-2 is isothermal;
- A pressure p_2

$$p_2 v_2 = RT_2 \Rightarrow p_2 = \frac{R \cdot T_2}{v_2} \tag{3}$$

At point 3

- A specific volume $v_2 = \frac{v_1}{\varepsilon}$ as the process **2 – 3** is isochoric;

- A pressure p_3

$$\frac{p_3}{p_2} = \lambda \Rightarrow p_3 = p_2 \cdot \lambda \tag{4}$$

An absolute temperature T_1

$$p_3 v_2 = RT_1 \Rightarrow T_1 = \frac{p_3 \cdot v_2}{R} \tag{5}$$

At point 4

- A specific volume is v_1 since process **4 – 1** is isochoric;

- An absolute temperature T_1 does not change as the process 3 - 4 is isothermal;

- A pressure p_4

$$\frac{p_3}{p_4} = \frac{v_1}{v_2} \Rightarrow p_4 = \frac{p_3 \cdot v_2}{v_1} \tag{6}$$

The expression determining the thermal efficiency of the Stirling cycle has the following form:

$$\eta_t = 1 - \frac{q_2}{q_1} = 1 - \frac{c_v \cdot (T_1 - T_2) + R \cdot T_2 \cdot \ln\left(\frac{v_1}{v_2}\right)}{c_v \cdot (T_1 - T_2) + R \cdot T_1 \cdot \ln\left(\frac{v_1}{v_2}\right)} \tag{7}$$

The presented algorithm allowed us to make a thermodynamic calculation of the ideal cycle of the external combustion rotary engine in accordance with the technical specification. For an ideal Stirling cycle, it is necessary to determine the thermodynamic parameters p_i, v_i and T_i of the state at all characteristic points of the cycle, specific amount of heat supplied q_1 and abstracted heat q_2, thermal efficiency of the cycle η_t and build this cycle in p, v coordinates if the pressure $p_1 =$ $1{,}7 \cdot 10^5$ Pascal, the absolute temperature $T_1 =$ **300 Kelvin**, and the degree of compression $\varepsilon = \frac{v_1}{v_2} = 2$, the degree of pressure increase $\lambda = \frac{p_3}{p_2} = 2.2$ are given. The working fluid is air with a gas constant $R =$ 287 $\frac{J}{kg \cdot K}$. The heat capacity of the working fluid was taken constant c_p = 1010 $\frac{J}{kg \cdot K}$, c_v = 721 $\frac{J}{kg \cdot K}$.

The results of the calculation are presented in table 1.

Table 1: The Thermodynamic Parameters of the Ideal Cycle State

Condition parameters	Point 1	Point 2	Point 3	Point 4
p_i, Pascal	$1.7 \cdot 10^5$	$3.4 \cdot 10^5$	$7.48 \cdot 10^5$	$3.74 \cdot 10^5$
v_i, $\frac{m^3}{kg}$	0.506	0.253	0.253	0.506
T_i, Kelvin	300	300	660	660

This cycle is built in p, v coordinates.

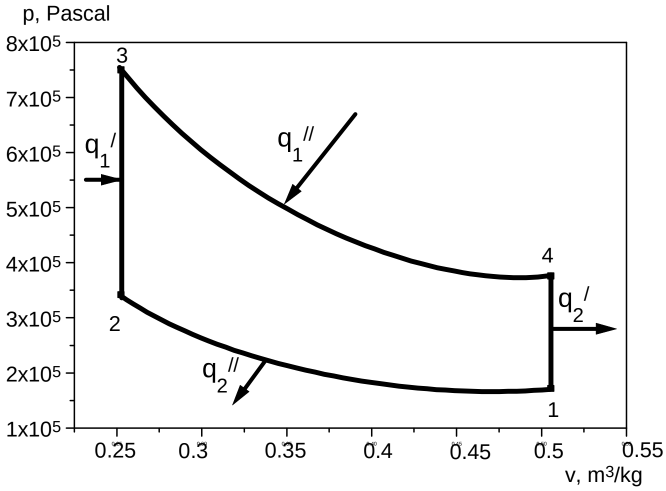


Figure 3: The Scheme of the Ideal Stirling Cycle in P, V Coordinates

Specific amount of applied heat

$$q_1 = q_1^/ + q_1^{//} = c_v \cdot (T_1 - T_2) + R \cdot T_1 \cdot \ln\left(\frac{v_1}{v_2}\right) = 721 \cdot (659.9 - 300) + 287 \cdot 659.9 \cdot \ln\left(\frac{0.506}{0.253}\right) = 3.9 \cdot 10^5 \frac{J}{kg}.$$

Specific amount of abstracted heat

$$q_2 = q_2^/ + q_2^{//} = c_v \cdot (T_1 - T_2) + R \cdot T_2 \cdot \ln\left(\frac{v_1}{v_2}\right) = 721 \cdot (659.9 - 300) +$$

$$+ 287 \cdot 300 \cdot \ln\left(\frac{0.506}{0.253}\right) = 3.19 \cdot 10^5 \frac{J}{kg}.$$

Useful specific amount of heat

$$q = q_1 - q_2 = 3.9 \cdot 10^5 - 3.19 \cdot 10^5 = 71000 \ \frac{J}{kg}.$$

Thermal efficiency of the Stirling cycle

$$\eta_t = 1 - \frac{q_2}{q_1} = 1 - \frac{3.19 \cdot 10^5}{3.9 \cdot 10^5} = 0.183 = 18.3\%.$$

DISCUSSIONS

The Stirling cycle is intended only for working with a gaseous working fluid. To accept optimal dimensions of the machines at a given power the pressure in the heat machine must be significantly higher than atmospheric. For the same reasons, the working fluid must have a low viscosity, a high thermal conductivity is possible, and finally the heat capacity is little dependent on pressure.

The performed thermodynamic analysis showed that this cycle is a direct cycle as a result of which the heat turns into work. The advantage of this cycle is the fact that it allows you to work in a large temperature range of hot and cold sources with relatively small pressures of pressure and expansion.

CONCLUSIONS

The design of a rotary engine with external heat supply has been developed. The thermal calculation allowed determining the basic thermodynamic parameters of the state and fairly accurately describing the operation of an external combustion rotary engine. The theoretical efficiency of the power plant is 18.3 %, which indicates the possibility of using this engine as a generator of thermal energy in the air heating system of buildings.

At the present moment a full-scale sample of the engine is made. And an experiment is planned to carry out a comparative analysis of the theoretical and experimental data.

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